1476 aaa 8

OBSERVATIONS

AND

CONJECTURES

ON THE

NATURE AND PROPERTIES

OF

LIGHT,

AND ON THE

THEORY of COMETS.

BY WILLIAM COLE.

COLCHESTER,
PRINTED AND SOLD BY W. KEYMER:
Sold alſo by Mr. FLETCHER, *Oxford*; Mr. PARIS,
Cambridge; Mr. MARTIN, Optician, *Fleet-Street*,
and Mr. ROBINSON, *Paternoſter-Row*, *London*.
MDCCLXXVII.

OBSERVATIONS AND CONJECTURES

ON THE

NATURE AND PROPERTIES

OF

LIGHT.

OF all the operations of nature that have engaged the attention of philoſophers, none have been more clearly explained, or more ſatisfactorily accounted for, than thoſe which relate to light and colours. The theory eſtabliſhed by Sir Iſaac Newton, upon the ſolid baſis of experiment and fact, ſeems to carry with it ſuch force of conviction, as is ſcarce poſſible to be reſiſted by an unprejudiced enquirer after truth. Objections however have been often ſtarted againſt this, as well as the other diſcoveries of our great philoſopher; and of late ſome opinions ſeem to have been gaining ground relating to this doctrine, which ſtrike at its root, or at leaſt tend to involve it in conſiderable obſcurity.

My deſign in the following papers is, to examine the force of theſe objections, and this chiefly in order to introduce ſome obſervations and conjectures which either ariſe from the Newtonian theory, or at leaſt tend to confirm and illuſtrate it. Premiſing however, that ſuch of them as do not appear to be ſufficiently warranted by experiment, I would wiſh the reader to conſider as *hypotheſes* merely, 'till they ſhall be either eſtabliſhed or exploded by further experiments.

Light, according to Sir Iſaac Newton's idea of it, conſiſts of inconceiveably ſmall particles of matter, which are emitted from a luminous body, in all directions, with an amazing velocity. This great philoſopher has intimated his opinion, that an elaſtic ſubtile medium, which he calls Æther, is expanded through the vaſt regions of ſpace, and pervades all bodies. Through this medium he ſuppoſes that the rays of light are conveyed from the ſun to the various parts of the ſyſtem; an idea however which he has profeſſedly given as an hypotheſis merely, and by way of ſuggeſting matter for further enquiry. Whether ſuch an elaſtic medium really exiſts, I certainly ſhall not take upon me to determine. Some late writers however, taking for granted the exiſtence of ſuch medium, have attempted to account for all the phænomena of light by its different modifications; and others have gone ſo far as to ſuppoſe that light is this very medium.

Dr. Wilſon particularly, in his Medical Reſearches, conſiders the particles of the æthereal medium and thoſe of light and heat as being one and the ſame; and upon this ſuppoſition endeavours to account for all their various phænomena.

But that this is not the caſe, is abundantly evident from many of the experiments upon which Sir Iſaac Newton has eſtabliſhed his theory; particularly from thoſe by which he has ſhewn, that the particles of light are of an heterogeneous nature. And indeed, this no-tion ſeems utterly inconſiſtent with that great philoſopher's idea of the æthereal medium; for he ſays, "that it pervades all bodies." *(a)* Whereas it is evident, that light may be inflected, reflected, or quite ſtopped, by the interpoſition of different bodies. This *hypotheſis* alſo ſeems not leſs inconſiſtent with Doctor Wilſon's own idea of this medium; for he ſuppoſes, that there is an abſolute plenum of the elementary matter which conſtitutes it. But ſurely it is extremely difficult, if not impoſſible, to conceive, that the particles of this matter, of which the univerſe is ſuppoſed to be full, can move with ſuch amazing velocity in all directions, as is known to be the fact with reſpect to light, without giving perpetual interruption to each others motions.

This *hypotheſis* has however been already reprobated by other writers. The London Reviewers, particularly, in their remarks on the above-mentioned publication, *(b)* ſay, "It is "this elementary medium to which our au"thor erroneouſly gives the name of light, "which is merely an affection, or mode of "motion

---

(a) Optics, Page 324. *(b)* London Review, Dec. 1776, p. 422.

"motion in it." And in the ſame remarks (a) they have given their own definition of light in the following words. "Light is (according to our notions) a vibratory motion propagated in right lines, through a ſeries of *elaſtic* bodies conſtituting the medium called æther, and that without poſſeſſing any property of *fire*, or generating any ſymptom of *heat*, unleſs ſuch motion be interrupted, and refracted by the interpoſition of gravitating bodies; for it is notorious from repeated experiments, that the rays of light paſs through a tranſparent fluid, nay, may be made to converge to a focus within ſuch a fluid without *heating* it." I cannot tell upon what experiments theſe Gentlemen found their notions, nor where they can find a "a tranſparent fluid" that is not compoſed of "gravitating bodies." But nothing ſeems more evident than that light cannot conſiſt merely in a motion or affection of any medium whatever. For in all vibratory motions, in an elaſtic medium, when any one particle is put in motion, it impels that which is contiguous to it, and that impels the next, and ſo on, expanding the motion in all directions through every part of the medium. This may be illuſtrated by the following ſimple and eaſy experiment.

(a) London Review, Dec. 1776, page 420.

Let A B C D (*Fig.* 1.) repreſent a pool, or piece of ſtill water, let this be divided into two parts, by two pieces of board, repreſented by E F and G H, leaving only a ſmall aperture F G; now if a ſtone, or heavy body be let fall into any part of it, ſuppoſe at I, it will excite a vibratory motion in the ſurface of the water, which motion will appear in concentric circles, expanding themſelves in every direction from the point I; but by the interpoſition of the partitions, E F, G H, theſe circles will be intercepted, except at the aperture F G, through which the vibrations will paſs, expanding themſelves again behind the partitions, in circles concentric to that of which the aperture is the diameter, and communicating the motion to every part of the ſurface.

Analogous to theſe, are thoſe vibrations of the air which excite our perceptions of ſound, with this difference, that the vibrations of the air expand themſelves in concentric ſpherical ſurfaces. For as Sir Iſaac Newton obſerves upon this very ſubject, *(a)* "a bell, or a "cannon may be heard beyond a hill which "intercepts the ſight of the ſounding body, "and ſounds are propagated as readily through "crooked pipes as through ſtraight ones." In the ſame manner muſt the vibrations expand themſelves in every other elaſtic medium, or ſuch wherein the particles *(b)* "reſiſt "each other on every ſide." Now it is evident, that light does not expand itſelf in this manner. For let I, *(Fig. 1.)* repreſent a luminous body, then will the light, from it, expand itſelf, 'till it is intercepted by the partitions E F, G H; but the rays I F, I G, after paſſing the aperture will not ſpread as before, but will paſs on *nearly* in a direct line to M and N, without expanding into any part of the ſhadow, unleſs they are reflected from ſome other body.

This idea of light ſeems alſo to be totally inconſiſtent with the moſt ſimple experiments, upon which Sir Iſaac Newton has founded his theory. For theſe experiments evidently prove, that the rays of light are differently refrangible, and conſequently that their component particles are heterogeneous, or of different magnitudes; that theſe different particles excite ſenſations of different colours, and may be ſeparated ſo as to exhibit any ſimple colour, or mixed ſo as produce all the degrees of colours that can be compounded of the ſimple ones. Now if light be only an affection, or "mode of motion" in the æthereal medium, we muſt of neceſſity ſuppoſe as many different kinds of vibration as there are different colours. But that ſuch different vibrations can be communicated through an elaſtic medium to ſuch vaſt diſtances, and yet preſerve their different properties ſimple and entire, ſeems hardly conceivable. And indeed all our obſervations on vibratory motion plainly contradict ſuch a ſuppoſition. For a great variety of vibrations of the air, generated by the percuſſion of a number of ſonorous bodies, excite very confuſed and indiſtinct perceptions. Thus, from a number of perſons talking together, no particular diſtinct perception will be excited, unleſs one voice predominate above the reſt. A ſimilar effect is produced by the ſinging of a great number and variety of birds in a wood; where only a very few of the moſt remarkable can be diſtinguiſhed.

(a) Optics, p. 327. (b) London Review, Dec. 1776, p. 422.

From theſe conſiderations it is evident, that light is not merely an affection, or mode of motion in any medium whatever; but that it conſiſts of real particles of matter projected from the luminous body.

The moſt remarkable properties of theſe particles have been inveſtigated by Sir Iſaac Newton, and other writers on optics; who, by a great number of experiments, have proved, that the rays of light are both reflexible and refrangible: that they are heterogeneous, as poſſeſſing different degrees of reflexibility, and refrangibility: that "every ray "in its paſſage through any refracting ſurface "is put into a certain tranſient conſtitution or "ſtate, which in the progreſs of the ray re-"turns at equal intervals, and diſpoſes the "ray at every return to be eaſily tranſmitted "through the next refracting ſurface, and "between the returns to be eaſily reflected

" by it," *(a)* which tranſient diſpoſitions are called fits of eaſy tranſmiſſion, and reflection: that the rays of light paſſing very near the edges of bodies are inflected or turned a little out of their direct courſe; and that the particles of light are propagated in time, ſo as to take up about ſeven minutes in paſſing from the ſun to the earth.

Of all the objections to this theory that I have met with, the moſt plauſible are thoſe advanced by Mr. Brydone, in his Tour through Sicily and Malta. And if this gentleman be not miſtaken in his ideas of the nature of light, his objections would, perhaps, be unanſwerable. To avoid any poſſible miſrepreſentation, it will be proper to take the objections in his own words, as given in the abovementioned work. *(b)* " It is ſomewhat " ſtrange" ſays he, " that of all that im-" menſe quantity of matter poured down on " us during the day, that pervades and fills " the whole univerſe; the moment we are " deprived of the luminous body, the whole " of it in an inſtant ſeems to be anihilated.

" In

(a) Newton's Optics, Prop. xii. page 253.

(b) Tour through Sicily and Malta, Letter 24th.

"In ſhort, there are a number of difficulties
"attending the common received doctrine of
"light; nor do I think there is any point
"in natural philoſophy the ſolution of which
"is leſs ſatisfactory. If we ſuppoſe every ray
"to be a ſtream of particles of matter, darting
"from the luminous body, how can we
"conceive that theſe ſtreams may be interſected
"and pierced by other ſtreams of the
"ſame matter ten thouſand thouſand different
"ways, without cauſing the leaſt confuſion
"either to the one or the other? For in a
"clear night we ſee diſtinctly any particular
"ſtar that we look it, although the rays
"coming from that ſtar to our eye, *is* pierced
"for millions of miles before it reaches us,
"by millions of ſtreams of the ſame rays,
"from every other ſun and ſtar in the univerſe.
"Now ſuppoſe, in any other matter
"that we know of, and one would imagine
"there ought at leaſt to be ſome ſort of analogy;
"ſuppoſe I ſay, we ſhould only attempt
"to make two ſtreams paſs one another;
"water, for inſtance, or air, the pureſt
"and moſt fluid matter that we know, we
"find it totally impoſſible. The two ſtreams
"will mutually interrupt and incommode one

“ another, and the ſtrongeſt will ever carry off the weakeſt in its own direction; but if a ſtream of light is hit by ten thouſand other ſtreams moving at the rate of ten millions of miles in a minute, it is not even bent by the impreſſion, nor in the ſmalleſt degree diverted from its courſe, and it reaches us with the ſame preciſion and regularity as if nothing had interfered with it at all. Beſides on the ſuppoſition that light is real particles of matter moving from the ſun to the earth, in the ſpace of ſeven minutes, how comes it to paſs, that with all this wonderful velocity there ſeems to be no momentum! for it communicates motion to no body that obſtructs its paſſage, and no body whatever is removed by the percuſſion. Suppoſing we had never heard of this diſcovery, and were at once to be told of a current of matter flying at the rate of ten million of miles in a minute, and ſo large as to cover one half of our globe, would we not imagine that the earth muſt be inſtantly torn to pieces by it, or carried off with the moſt incredible velocity? It will be objected, that the extreme minuteneſs of the particles of light prevents it from

" having any ſuch effect; but as theſe parti-
" cles are in ſuch quantity, and ſo cloſe to
" each other as to cover the ſurface of every
" body that is oppoſed to them, and entirely
" to fill up that vaſt ſpace betwixt the earth
" and the ſun, this objection I ſhould think
" in a great meaſure falls to the ground.
" The particles of air, and of water are like-
" wiſe extremely minute, and a ſmall quan-
" tity of theſe will produce little or no effect,
" but increaſe their number, and only give
" them the millionth part of the velocity that
" is aſcribed to a ray of light, and no force
" whatever could be able to withſtand them."

However ſpecious theſe objections may at firſt ſight appear, upon a more deliberate conſideration we ſhall poſſibly find, that they are founded on miſtaken notions. But before I attempt to correct the general idea on which they are founded, it may not be amiſs juſt to take notice of a miſtake in this deſcription of the effects produced by the rays of light. It is ſaid, that from the wonderful velocity of the rays of light, " there ſeems to be no momen-
" tum; for it communicates motion to no
" body that obſtructs its paſſage, and no body
" whatever

"whatever is removed by the percuſſion." This is certainly an overſight. For nothing is more certain, than that the rays of light communicate motion to thoſe bodies in which they produce heat. This motion is much more ſenſible, when the rays are collected by a burning glaſs; for then the body actually takes fire, and the particles of it fly off in flame or ſmoke.

It muſt, however, be confeſſed, that the effect of this momentum is very inconſiderable, in proportion to what might be expected from it, if light, according to Mr. Brydone's idea of it, were a fluid, or if the particles of it were "ſo cloſe to each other, as entirely "to fill the vaſt ſpace betwixt the earth and "the ſun." For, if this were the caſe, no force indeed could be able to withſtand it; and, admitting this ſuppoſition, the whole of the Newtonian theory muſt fall to the ground. But it does not appear that Sir Iſaac Newton ever conſidered light as a fluid; nor indeed does ſuch an idea ſeem to be conſiſtent with any of the phænomena. It may be aſked then, if light be not a fluid, what is it? and how happens it, that the rays, in paſſing through the vaſt regions of ſpace, do not obſtruct each others motion? Theſe queſtions, with others that naturally ariſe from them, I ſhall endeavour to anſwer in ſuch a manner as, to me, appears conſiſtent with the phænomena, and known experiments; leaving it to thoſe who have ability and inclination to proſecute theſe ſtudies, either to confirm, or diſprove what is here advanced, by future experiments and obſervation.

Light then, I apprehend, poſſeſſes none of the properties of a fluid; but conſiſts of ſolid bodies, or particles of matter, projected from the luminous body, and ſucceeding each other in right lines. For if light were a fluid, the rays, or ſtreams, muſt, according to the foregoing objection, certainly obſtruct each other in their paſſage. The ſame objection would alſo obtain, if the particles that compoſe a ray of light be ſuppoſed to follow inſtantaneouſly, or to be contiguous to each other. Now there are many obſervations which ſtrongly incline us to think, that they do not follow inſtantaneouſly, but ſucceed each other at conſiderable diſtances.

In the firſt place, the great Author of Nature has ſo formed our organs of ſight, that the inſtantaneous ſucceſſion of the particles in a ray of light is not neceſſary to produce diſtinct viſion. For the impreſſions made by a ray of light upon the retina, and communicated from thence to the brain through the optic nerve, are of a laſting nature; and therefore if a ſecond particle ſucceeds before the the impreſſion made by the firſt ceaſes, the viſion will be as diſtinct as if the ſucceſſion were inſtantaneous. Now as the all-wiſe Author of our being has made no part of our frame without its uſes, it is reaſonable to ſuppoſe, that this would not have been the conſtruction of the organ, if there had been no neceſſity for it; and it does not appear, that there would be any ſuch neceſſity, if the particles of light were contiguous, or ſucceeded each other inſtantaneouſly. Therefore we may with great reaſon conclude, that the particles do in fact ſucceed each other at conſiderable diſtances.

But it will be worth while to examine this matter further, and endeavour to find out, nearly, the diſtances at which the particles may ſucceed; and this may be done by the following eaſy and ſimple experiment. Let a burning coal be moved round in the circumference of a circle, with ſuch a velocity as to make one revolution in about one fourth of a ſecond of time, then a beholder will ſee an entire circle of fire; conſequently the impreſſions on the retina continue during one revolution of the coal, or about one fourth of a ſecond of time. *(a)*. Hence it appears, that if the particles of light ſucceed each other every quarter of a ſecond, the viſion will be diſtinct. But we will ſuppoſe the particles to ſucceed much quicker, and to ſtrike the retina an hundred times in a ſecond, or ſix thouſand times in a minute. Now as light is about ſeven minutes in paſſing from the ſun to the earth, or about eighty one millions of miles, we find, that, according to this ſuppoſition, the particles will ſucceed each other at a diſtance of near two thouſand miles.

If then we conſider the particles of light as ſucceeding each other at this diſtance, the greateſt part, if not all, of Mr. Brydone's

objections

(a) The effect would be the ſame if the revolutions were much ſlower; and Sir Iſaac Newton ſuppoſes that the impreſſions continue nearly a ſecond.

objections entirely vaniſh. For though the ſucceſſion in reſpect to time be almoſt inſtantaneous, yet the diſtance of the particles from each other being very conſiderable, it will be eaſily conceived, that the ſeveral rays, or ſtreams of ſuch particles, may paſs through the vaſt regions of ſpace without any ſenſible obſtruction. For though ſome of the particles may poſſibly ſtrike others in their paſſage, yet if only one particle in twenty, paſſing in the ſame direction, arrives at the eye uninterrupted, the viſion will be diſtinct and perfect. (*a*)

Hence alſo we ſee the reaſon why the momenta of the particles of light produce no greater effects. For the motion excited by one particle in ſome meaſure ſubſides before a ſecond particle ſucceeds; and in the interval between theſe ſucceſſive ſtrokes, the particles of the body upon which the light falls will be reſtored to their former ſituation, by their own elaſticity, and alſo by the percuſſion of the adjacent rays. The particles of the body, being thus alternately impelled and reſtored, will be put into a vibratory motion, like that whereby

C

(*a*) See page 17.

whereby heat is excited, or wherein it is ſuppoſed by ſome to conſiſt.

But it may be objected, that this concluſion cannot univerſally obtain. For even if it be granted, that the particles in a ray of light coming from the ſun, or any other very diſtant luminous body, may poſſibly ſucceed each other at a diſtance equal to that above-mentioned, yet this cannot be the caſe with reſpect to thoſe rays which are emitted from very near luminous bodies. For inſtance, the particles iſſuing from a candle, ſituated within a few feet of the eye, can never be two thouſand miles diſtant from each other. In anſwer to this let it be obſerved, that though the particles of light, which in this inſtance fall upon the eye, never can be in fact at any conſiderable diſtance from each other, yet thoſe particles which are not intercepted may ſucceed each other at a diſtance nearly equal to that above-mentioned; and therefore every particle which ſtrikes the eye is intercepted before the next ſucceeding particle is emitted from the candle. To illuſtrate this, ſuppoſe a number of balls to be ſucceſſively projected from a cannon, with a velocity ſufficient to carry them five hundred feet in a ſecond of time; now if we ſuppoſe the cannon capable of being diſcharged once every ſecond, it is evident that, if the balls are not interrupted, they will ſucceed each other at the diſtance of five hundred feet. But let an obſtacle ſufficient to reſiſt the force of the ball be interpoſed at the diſtance of twenty feet from the cannon, then every ball will ſtrike the obſtacle before the next ſucceeding one leaves the cannon; and though the balls in this caſe can never be further from each other than twenty feet, yet the effect on the obſtacle will be the ſame as if they actually ſucceeded each other with the ſame force, at the diſtance of five hundred feet. Thus, though the particles emitted from a luminous body ſucceed each other at very great diſtances, yet if an eye is ſituated at a leſs diſtance from the body than the ſucceſſive diſtance of the particles, every particle which ſtrikes the eye muſt be intercepted, before the next ſucceeding particle is emitted from the body; and the effect will be juſt the ſame as if ſeveral of thoſe particles were actually in motion at the ſame time.

As the particles of light are projected from the luminous body in right lines, it is evident, that the rays will ſpread, or ſeparate from each other in their paſſage, and that the intenſity of the rays of light acting upon any body will be reciprocally as the ſquare of the diſtance from the luminous body. It is therefore probable, that, at an inmenſe diſtance from the luminous body, the rays will be ſo far ſeparated, that the diſtance of the neareſt two of them may exceed the diameter of the pupil of the eye, and conſequently the eye not be able to take in more than one of them at the ſame time. Hence we may account for a very common phænomenon, which otherwiſe ſeems not eaſily explained, viz. the appearing and diſappearing of very diſtant luminous bodies. Let a perſon in a clear night fix his eye upon a very diſtant ſtar; or ſuch an one as can juſt be diſcerned with the naked eye; then while he keeps his eye fixed, he will have the ſtar *almoſt* continually in view, but upon the leaſt motion of his head or body, the ſtar generally diſappears, and it will be ſome conſiderable time before he can ſee it again. This, no doubt, is owing to the diſtance of the ſeveral rays from each other, as the phænomenon is moſt obſervable at the greateſt diſtance from the luminous body. It may here alſo be obſerved, that if light were a fluid, or if the particles were contiguous, no ſuch phænomenon could happen.

If any of the particles in a ray of light are ever interrupted by other rays, the greater the diſtances are through which the rays paſs, the greater number of particles will, without doubt, be ſtopped in their paſſage, and conſequently thoſe that are not interrupted will ſucceed each other at greater diſtances. Now if a perſon, as before-mentioned, keeps his eye fixed on a very diſtant ſtar, it will ſometimes diſappear, and appear again, alternately. This may poſſibly be owing to the ſlower ſucceſſion of the particles in the ſame ray; though perhaps it may be difficult to determine, whether it is ſolely owing to this cauſe, or whether it may not alſo be in ſome meaſure occaſioned by a defect, or ſome ſmall motion of the eye.

Perhaps it may be objected, that if the particles of light were ſolid bodies, they would gravitate towards the ſun and the earth, and towards each other in the ſame manner as other bodies do. And doubtleſs this is the caſe. But when we conſider the minuteneſs of the particles, and their amazing velocity, this objection entirely vaniſhes. For even if we ſuppoſe a particle of light, in its paſſage from the ſun to the earth, to be acted upon by a gravitating power equal to that at the ſurface of the earth, and in a direction perpendicular to that of the ray; the particle by this action would be drawn out of its true place but little more than five hundred miles: which, at the diſtance of the ſun, can ſubtend but an exceeding ſmall angle, and conſequently could produce no ſenſible effect. But when we conſider, that the gravitation on the particles acts nearly in the direction of the rays, it will evidently appear that the perturbation, occaſioned by ſuch a power, muſt be altogether inconceivable.

But, as Mr. Brydone obſerves, it may appear "ſomewhat ſtrange, that of all the im-"menſe quantity of matter poured down on "us during the day, the moment we are de-"prived of the luminous body, the whole of "it, in an inſtant, ſeems to be annihilated."

Now may we not reaſonably ſuppoſe, that the lucidity of the particles of light depends on their velocity? and that when their velocity is diminiſhed beyond a certain degree, they are no longer luminous? If this ſuppoſition be granted, the above-mentioned difficulty is eaſily overcome. And it ſeems to be conſiſtent with all the obſervations that we are able to make. Let a portion of light be admitted through a ſmall hole into a room, otherwiſe totally dark, and hung with black; then if the light thus admitted be received upon the black ſurface, very little, if any, of it will be reflected into the other parts of the room. Whence it is evident, that the particles of light, which fall upon that ſurface, are chiefly abſorbed by it, and are refracted and reflected within its ſubſtance 'till all their velocity is loſt. Let the light be thus admitted for ever ſo long a time, and then if the hole be ſtopped, the room will become, in an inſtant, as dark as it was before any light was admitted, and the part on which the light was received will be equally dark with the other parts of the room. Now as a vaſt number of particles muſt be abſorbed by the ſurface on which the light was received, there would neceſſarily be ſome appearance in this ſurface different from the other parts of the room, if thoſe particles retained any of their luminous quality. But as no ſuch luminous appearance remains, and as we know of no alteration that the particles can have undergone by falling upon ſuch a ſurface, except a diminution of their velocity, or a total extinction of their motion, may we not from hence conclude, that when the motion of the particles of light is extinct, or its velocity diminiſhed beyond a certain degree, they are no longer luminous, but become of the ſame nature with the particles of thoſe bodies, with which they to all appearance incorporate.

This ſeems to have been the opinion of Sir Iſaac Newton; for he ſays, (a) "Do not "bodies and light act mutually upon one ano-"ther; that is to ſay, bodies upon light in "emitting, reflecting, refracting, and inflect-"ing it, and light upon bodies, for heating "them, and putting their parts into a "vibrating motion wherein heat conſiſts?"

(a) Optics, page 314. Qu. 5.

" ſiſts *(a)*?" Again, *(b)* " Do not all fixed " bodies, when heated beyond a certain de- " gree, emit light and ſhine; and is not this " emiſſion performed by the vibrating mo- " tions of their parts?' And again he ſays, *(c)* " Are not groſs bodies and light converti- " ble into one another, and may not bodies " receive much of their activity from the par- " ticles of light which enter their compoſi- " tion? For all fixed bodies being heated emit " light ſo long as they continue ſufficiently " hot, and light mutually ſtops in bodies as " often as its rays ſtrike upon their parts." Now if bodies, by being put in motion, or by being heated in a certain degree, become luminous, may we not conclude, that when the particles, thus emitted, loſe their motion, or a certain degree of their velocity, they likewiſe loſe their lucidity; and that the luminous quality in the rays of light depends entirely on their velocity.

(a) Whether heat in bodies be produced by an inteſtine motion of their parts merely, or by an elementary principle put in action by ſuch motion, is of no conſequence to our preſent enquiry. It is certain, that heat does not exiſt without motion; and therefore, upon either ſuppoſition, our arguments hold equally good.

(b) Optics Page 314. Qu. 8. *(c)* Optics Page 349. Qu. 30.

If a very great diminution of velocity in the rays of light entirely deprives them of their lucidity, then every partial diminution of their velocity muſt render them in ſome degree leſs luminous. And this appears to be agreeable to obſervation. For it is well known, that light in paſſing through a denſe medium loſes a conſiderable part of its luſtre, though that medium be very tranſparent. Now as it is reaſonable to ſuppoſe, that the particles meet with ſome reſiſtance in paſſing through ſuch a medium, it is probable, that their velocity is thereby diminiſhed.

It may be objected, that the diminution which light ſuffers, in paſſing through a tranſparent, denſe medium, is owing to the loſs of a great number of particles, which are reflected back by the ſurfaces of the medium. And there is no doubt but light ſuffers a conſiderable diminution in this way. However there is great reaſon to think, that this is not the ſole cauſe; but that the diminution of the light is in part owing to the check which its velocity ſuffers in paſſing through ſuch medium. For the light that is tranſmitted through a thin piece of glaſs is brighter than that

tranſ-

tranſmitted through a thick one, ſuppoſing the glaſſes to be equally clear; though it is certain that no more particles are reflected from the ſurfaces of the latter, than from thoſe of the former.

But if the velocity of light be retarded, as is here ſuppoſed, in its paſſage through a denſe medium, and it thereby becomes leſs lucid, then its luſtre muſt be in ſome meaſure diminiſhed by its paſſage through the atmoſphere; and objects eſpecially the heavenly bodies, will be leſs bright when viewed from a low ſituation, than when viewed from an eminence. And that this is really the caſe, we learn from the obſervations of thoſe who have aſcended to the ſummits of lofty mountains. This circumſtance was remarked by Mr. Brydone, when at the top of mount Ætna; and the brightneſs of the heavenly bodies viewed from thence far exceeded their greateſt degree of brightneſs, when ſeen from the lower parts of the atmoſphere. "We "obſerved", ſays he, *(a)* "with aſtoniſhment, that the number of the ſtars ſeemed "to be infinitely increaſed, and that the "light

---

(a) Tour through Sicily and Malta, Vol. I. Page 184.

"light of each of them appeared brighter "than uſual. The whiteneſs of the milky "way was like a pure flame that ſhot acroſs "the heavens; and with the naked eye we "could obſerve cluſters of ſtars that were "totally inviſible in the regions below." Theſe obſervations then appear to be perfectly conſonant to our hypotheſis. For as there can be little doubt, that the velocity of light muſt be conſiderably retarded by its paſſage through a refracting medium, like the atmoſphere, ſo it is highly probable, that the diminution of its luſtre is owing, in a great meaſure, to ſuch diminution of its velocity. It may be objected, that, if the velocity be greater, the heat, as well as the light, ought to be more perceptible at the top of the mountain than at the bottom; whereas the fact is directly contrary. In anſwer to this, let it be conſidered, that the heat in lower ſituations is not occaſioned merely by the number of the direct rays falling upon a given ſurface; for if this were the caſe, the heat would be rather leſs in the vallies than on the top of the higheſt mountain. But it is more probable, that the particles of the atmoſphere being agitated by the rays of light, and put into a kind of vibratory motion, the motion is communicated from one particle to another, and the heat thereby expanded through every part of the atmoſphere. We may obſerve ſomething like this in many other caſes. For inſtance, if the end of an iron bar be heated, the motion, or the power of exciting the ſenſation of heat, will be communicated, in a conſiderable degree, through the parts of the iron, quite to the other end of the bar. Hence it appears, that the more denſe the atmoſphere, the greater will be the agitation produced amongſt its particles; and in conſequence a greater ſenſation of heat will be excited in the lower parts of the atmoſphere, than is ever excited in the higher parts of it, in the ſame climate, and at the ſame time. Other reaſons might alſo be aſſigned, why the heat is greater in lower ſituations, than on the tops of mountains; but theſe it is not within our preſent purpoſe to examine.

From theſe obſervations we may infer, that the effects produced on different bodies, by the action of the particles of light, are the greateſt on ſuch bodies as reflect or tranſmit the leaſt quantity of them, and that a greater motion is excited, by the percuſſion of the particles, in ſuch bodies, than in thoſe that reflect, or tranſmit the rays more copiouſly. For the motion of thoſe particles which enter the ſubſtance of bodies being deſtroyed, an equal quantity of motion muſt neceſſarily be communicated to the particles of ſuch bodies, and conſequently a greater motion muſt be excited than where the particles are tranſmitted, or are turned back before they even touch the ſurface *(a)*. And this upon examination we ſhall find to be the caſe; for we find, that black bodies take fire ſooner than white ones, and opaque ſooner than tranſparent; as may be eaſily proved, by making a black ſpot on a piece of white paper, and bringing the rays, collected in the focus of a burning glaſs, to fall, ſome on the black, and others on the white part of the paper. And indeed the fact is, that the whiteſt paper, and perhaps all bodies whatever, become black before they take fire.

As

(*a*) It is well known, that the reflection of the rays of light is not cauſed by their impinging upon the ſurface, but by a reflecting or repelling power, that acts at ſome little diſtance from it.

As light and heat are in general produced by the ſame bodies, it may ſeem difficult to conceive the reaſon, why ſome bodies, which produce a conſiderable degree of light, do not excite any ſenſible heat; and why others, on the contrary, excite a great degree of heat without light. From what we have advanced it ſeems probable, that the ſame particles would always excite ſenſations both of light and heat, if they were to ſtrike the body with a certain degree of velocity, and in a certain quantity.

In order to illuſtrate this, let us ſuppoſe a ball of iron to be heated to an intenſe degree; then the particles of the iron will be put into a violent inteſtine motion, and a great number of particles will alſo be emitted from it, which, if the ball is in a darkened room, will excite ſenſations both of light and heat. While the heat of the body continues the ſame, the ſenſation of light remains unaltered; but if the body be ſomewhat cooled, the ſenſation of light will alſo be diminiſhed. Thus, as the ball cools, the light gradually diminiſhes, 'till the ſenſation of it is entirely loſt; but ſtill after the light is gone, the ſenſation of heat continues in a very conſiderable degree. Now there ſeems to be no poſſible way of accounting for theſe different effects of light and heat produced by the ſame particles emitted from the ſame body, but by ſuppoſing that, as the body gradually cools, the particles are emitted with a gradual decreaſe of velocity, and that, after the diminution of their velocity to a certain degree, they are no longer capable of exciting the ſenſation of light, though they ſtill retain the power of exciting that of heat. This will appear further evident, if we conſider, that from thoſe bodies which produce both light and heat the light is perceptible to a much greater diſtance than the heat. And conſequently, the number of particles received on a given ſurface being inverſely as the ſquare of the diſtance, the ſenſation of light is excited by a leſs number of particles than that of heat. Again, let it be conſidered, that, at whatever diſtance the light is perceptible, the luminous body appears with a nearly equal degree of brightneſs; and that, if the light becomes imperceptible at a great diſtance, it becomes imperceptible at the leaſt diſtance almoſt at the ſame inſtant. But it is not ſo with reſpect to heat. For if, as the body cools, the heat becomes imperceptible at any one conſiderable diſtance, yet by moving nearer to the body, ſo that a greater number of particles fall on a given ſurface, the heat again becomes perceptible; and as we gradually move ſtill nearer to the body, we find a gradual increaſe of the heat. All which ſeems evidently to ſhew, that the ſenſation of light depends entirely on the velocity of the particles; while that of heat ſeems to depend on the number of the particles, compounded with their velocity; ſo that the intenſity of the heat excited on a given ſurface, in a very ſmall inſtant of time, is as the momenta of the particles which ſtrike that ſurface in that inſtant. *(a)*

(a) What is the particular cauſe, that the ſame particles, which, according to their different modifications, produce either heat, or light, or both, are emitted with greater velocity from ſome bodies than others, is another queſtion. Bodies when inflamed produce a proportionally greater degree of light than of heat. Bodies not inflammable the reverſe. Inflammation, it is well known, is producod by a decompoſition of the phlogiſton, which enters, more or leſs, into the compoſition of all inflammable bodies. Do not the particles of the phlogiſton, when thus decompoſed, acquire a greater, or leſſer degree of activity, as the decompoſition

From theſe ſeveral obſervations then it is evident, that light is compoſed of ſolid particles of matter projected from the luminous body in right lines, and ſucceeding each other at very conſiderable diſtances; and it is probable, that the lucidity of the rays depends principally, if not entirely on their velocity,

---

is more or leſs perfect, and are they not emitted from the inflamed body with a proportional degree of velocity ? The light produced by bodies not inflammable, when in the higheſt ſtate of ignition, is very inconſiderable compared to that produced by bodies of equal ſurfaces in a ſtate of inflammation. But the decompoſition here is alſo inconſiderable, and very imperfect, though the inteſtine agitation be prodigious. And do not all theſe circumſtances ſeem clearly to ſhew, that the greater or leſſer velocity of the particles emitted is owing to the more or leſs perfect decompoſition, as the greater or leſſer degree of light is owing to their greater or leſſer velocity ? It clearly appears from an experiment made by Dr. Fordyce, that the light, produced by by phoſphorus, is cauſed by the decompoſition of the phlogiſton, and that there is an actual inflammation (a). In this inſtance, very little or no heat is produced. Does not this ſeem to ſhew, that the decompoſed particles of phlogiſton are emitted with a velocity ſufficient to excite the ſenſation of light, but that the quantity emitted is not ſufficient to excite that of heat ? and conſequently does it not tend to confirm our general theory ?

(a) Philoſoph. Tranſact. Vol. 66. Page, 504.

and that thoſe bodies which ſhine without ſenſible heat do not emit a ſufficient quantity of particles to produce heat, while thoſe that excite heat without light do not project their particles with a velocity ſufficient to render them luminous. Theſe concluſions do not at preſent appear to be inconſiſtent with obſervation and known experiments; how far, by future experiments, they may be found to correſpond with the phænomena, and the real operations of nature, I leave to the determination of thoſe who have ability and inclination to proſecute theſe enquiries.

From theſe obſervations, however, we may infer the abſurdity of thoſe who contend for a plenum of matter throughout the vaſt regions of ſpace; ſince not only the planets, but the minute particles of light, perform all their various motions with the greateſt freedom; which they could not poſſibly do but in a vacuum. (a) Thoſe alſo, who ſuppoſe the ſpace between the ſun and the planetary orbits to be filled with particles of light, ſeem to be much miſtaken; for, as we have obſerved, the particles of the ſame ray may be ſome thouſand miles diſtant from each other, though with reſpect to time their ſucceſſion is almoſt inſtantaneous. And here I cannot but obſerve, that as, when we contemplate the works of creation in the conſtruction of the planetary ſyſtem, and the ſtupendous parts of the univerſe, we are ſtruck with admiration at their magnitude, together with the order and regularity of their motions, ſo, when we deſcend the ſcale of nature, and contemplate the minutiæ of material objects, we diſcover an equal harmony and beauty in their diſpoſition, and are equally loſt in wonder! Thus, when we conſider the minuteneſs of the particles of light, the amazing velocity with which they traverſe the vaſt regions of ſpace, and that without impeding each others motion, nay perhaps

---

(a) I own I was never able to conceive the poſſibility of any motion at all, or of the removal of a body from one portion of ſpace to another, without ſuppoſing ſome parts of ſpace to be abſolutely unoccupied by any body. Neither could

could I ever conceive, that there could be different degrees of denſity in bodies, where every thing was abſolutely, and therefore equally, full: where every particle touched its contiguous particles in all points of its ſurface. After the utmoſt effort of my imagination, I can form no idea of a plenum, but that of one uniform, motionleſs, and impenetrable maſs.

perhaps without ever touching each other, we diſcover ſuch a diſplay of infinite power and wiſdom, as muſt excite, in every rational being, the moſt exalted ideas of the Great Creator; while at the ſame time we are led to ſee the narrow limits of human knowledge, and are conſtrained to exclaim, "Lo, theſe "are part of his ways, but how ſmall a portion is known of him?"

OBSERVATIONS AND CONJECTURES ON THE THEORY OF COMETS.

THERE are no phænomena in nature that attract our attention more powerfully than thoſe of comets, when they deſcend into the viſible parts of our ſyſtem. The ſingular appearances of theſe bodies have given riſe to various conjectures concerning them; and while the vulgar beheld them with terror, and conſidered them as portending the moſt direful events, philoſophers have viewed them with agreeable ſurprize, and have endeavoured, by various hypotheſes, to account for the ſeeming irregularity of their motions. Theſe attempts, however, met with little ſucceſs, 'till Sir Iſaac Newton and his cotemporaries diſcovered, that the comets were large bodies revolving about the ſun; and finding, as far as their obſervations reached, that their motions were regulated by the ſame invariable laws that govern the motions of the planets, were naturally led to conclude, that they deſcribed very excentric elliptical orbits, and returned after determinate periods of time. Upon this principle later aſtronomers have endeavoured to calculate the dimenſions of ſeveral of their orbits, and to predict the time of their return. But as theſe bodies appear to us at very diſtant intervals, our accounts of them are ſtill extremely imperfect; and, the return of ſome of them not having anſwered the prediction of aſtronomers, there is reaſon to doubt the truth of the theory; though it is certain, that, when they deſcend into the planetary regions, they gravitate towards the ſun, according to the ſame laws that govern the revolutions of the planets.

A remarkable comet was obſerved at Palermo by Mr. Brydone, the ſingular appearance

pearance of which induced that gentleman to ſuſpect the truth of the cometary theory, and he has given us many ingenious remarks on this ſubject. *(a)* I cannot however but think, that he is miſtaken in ſome of his conjectures; as many of his objections equally affect the eſtabliſhed theory of the planetary motions, and indeed ſeem directly contrary to the known laws of nature. It is not my deſign to follow Mr. Brydone through all his objections, but only to take a little notice of one or two of the moſt remarkable, and to add a few conjectures on the motions of comets in general.

A partiality for a particular tenet is a very frequent ſource of error, and an over-fondneſs for a particular branch of philoſophy has induced many perſons to attempt the explanation of all the phænomena of nature by ſome particular favourite principle. And it ſhould ſeem, that it was ſome ſuch partiality, which led Mr. Brydone to attempt the explanation of the cometary motions on the principles of electricity. For ſays he, "Had the ſyſtem "of electricity, and of repulſion as well as

---

(a) Tour through Sicily and Malta, Letter, 24.

" attraction, been known and eſtabliſhed in
" the laſt age, I have little doubt that the
" profound genius of Newton would have
" called it to his aid; and perhaps accounted,
" in a more ſatisfactory manner, for the great
" phænomena of the heavens".

But what Mr. Brydone ſeems to conſider as the greateſt difficulty, in the received theory of a comet's motion, is the manner of accounting for its receſs from the ſun, after it has paſſed its perihelion; which receſs he ſuppoſes could not take place, except in conſequence of a repulſive force. For ſays he,
" I cannot help thinking it ſomewhat diffi-
" cult to conceive, that gravity ſhould always
" get the better of the centrifugal force at the
" very time that its action is the ſmalleſt,
" when the comet is at its greateſt diſtance
" from the ſun; and that the centrifugal force
" ſhould always get the better of gravity at
" the very time that its action is the greateſt,
" when the comet is at its neareſt point to
" the ſun. To a common obſerver it would
" rather appear, that the ſun, like an electric
" body, after it had once charged the objects
" that it attracted, with its own effluvia, or
" atmoſphere,

" atmoſphere, by degrees loſes its attraction, " and at laſt even repels them, and that the " attracting power, like what we obſerve in " electricity, does not return again 'till the ef- " fluvia imbibed from the attracting body is " diſpelled, or diſſipated, when it is again " attracted, and ſo on alternately; for, at " leaſt to an unphiloſophical obſerver, it really " appears ſomewhat repugnant to reaſon, to " ſay that a body flying off from another " body, ſome thouſands of miles in a minute, " ſhould all the time be violently attracted " by that body, and that it is even by virtue " of this very attraction that it is flying off " from it; he would probably aſk,—what " more could it do pray, were it really to be " repelled?"

Mr. Brydone here ſeems to ſuppoſe, that, according to the received theory, it is by virtue of the attractive force alone that a comet recedes from the ſun. But in this he is altogether miſtaken. For, by the principles of that very theory, if this force alone were to act, the body muſt fall directly to the center. It is one of the primary axioms of nature, that matter has no power in itſelf, to change its ſtate either of reſt or motion. (a) A body therefore, revolving about a center of attraction, muſt firſt have received an impulſive force in ſome direction different from that of the attraction.

(a) It ſeems, that there are ſome perſons who will not admit this as an axiom. For ſince I wrote the above, the Appendix to the firſt Volume of the London Review fell into my hands; where, in the catalogue of foreign books, I obſerved one entitled, "Obſervations on the Modern Carte-"ſianiſm," by M. Keranflech. The author of this work is ſaid to object to Sir Iſaac Newton's philoſophy, "for "want of a principle of action to keep his inert matter in "motion." Theſe reviewers ſeem alſo to be much of the ſame opinion; for ſay they, "It is very juſtly he "(M. Keranflech) obſerves, that a principle of *impulſe* has "as neceſſary and actual exiſtence in nature as attraction." That a principle of impulſion, or rather of repulſion, actually exiſts at or near the ſurface of ſome particular bodies, is certain; but that ſuch a principle is at all neceſſary "to "keep inert matter in motion," I muſt deny. For if matter required any ſuch principle to keep it in motion, it could not be inert; but muſt have ſome power, or principle, in itſelf, to diminiſh its motion, which this impellent principle is to counteract. But ſurely there wants very little penetration to diſcover the abſurdity of this ſuppoſition. It is a fact, that a body in motion requires juſt as much force to ſtop it, as was neceſſary at firſt to put it in motion. Suppoſe a body in motion to meet an equal body, moving with the ſame degree of velocity in a contrary direction; then, if the bodies are non-elaſtic, it is well known, that the motion of both will be deſtroyed; but if the velocity, or

---

or the quantity of matter of one body exceeds that of the other, though in the leaſt degree, the greater body will overcome the force of the leſſer, and carry it on in its own direction. It is alſo a fact, that a body in motion always proceeds in a right line, and deſcribes equal ſpaces in equal times, unleſs it be obſtructed, or its direction changed, by ſome extraneous cauſe. What then is the cauſe of this continuance of motion? We ſay, that the original impulſe alone produces it, and that no continuation of impulſe can act ſo as to produce theſe effects, and conſequently that no ſuch impelling principle does or can exiſt. There is no principle in nature, that acts upon bodies in motion, which does not act with, at leaſt, equal force upon bodies at reſt. If therefore ſuch an impelling principle really exiſted, no body could continue at reſt, unleſs it were acted upon, or ſupported by ſome external cauſe, in a direction oppoſite to that of the impulſive force. Again, we find, that all bodies put in motion by an external impreſſed force continue in the direction of the firſt impulſe; and if, by another impulſe, they are turned into another direction, they then as invariably purſue the line of the laſt direction. But why ſuch a principle of continued impulſe, as is ſuppoſed, ſhould act in the line of the firſt direction, rather than any other, and when the direction of the body is altered, why this principle ſhould immediately change its firſt direction, and follow the new direction of the body, I believe no one can

aſſign

traction. And this impulſive force being once communicated, its effect upon the body can never be totally deſtroyed, unleſs it be obſtructed by an equal force, either acting in, or reducible to, an oppoſite direction. At every ſucceſſive inſtant in which the central force acts, there commences a new combination of forces,

---

aſſign a reaſon, without having recourſe to the pre-eſtabliſhed harmony of *Leibnitz*, or ſome other doctrine equally viſionary and abſurd. It is further evident, that no ſuch principle of impulſe can poſſibly act upon bodies in motion; for, if that were the caſe, the motion of all bodies would be continually accelerated. If a body moving with a given velocity be acted upon by an impulſive force in the ſame direction in which the body moves, that impulſive force muſt either generate an increaſe of velocity at every inſtant, and ſo produce an accelerated motion, or produce no effect at all. But it is notorious, that bodies in motion are not thus accelerated, except in the particular caſe of attraction, or gravitation; and to ſay, that a force of any kind produces no effect, is to ſay, in other words, that it does not exiſt. If it be farther urged, that the action of this principle only ſupplies the defect of motion which the body loſes; this is either to uſe words without meaning, or to take that for granted which was to be proved, viz. that there is any loſs of motion. But even ſuppoſing ſuch loſs, how this principle can juſt ſupply that defect, and no more, in all degrees of motion, ſeems as difficult to conceive, as that it ſhould follow every new direction of the body.

forces, viz. of that in conſequence of which the body was moving at the inſtant of the preceding combination, and of the central. And the effect is preciſely the ſame, as if at every ſuch period the former of theſe forces was ſuppoſed to ceaſe, and a new impulſe to be given in the ſame direction, and producing the ſame degree of velocity; or, as if every ſucceſſive period of the revolution were in fact an original projection. For the force compoſed of the two preceding forces at any given inſtant, after ſuch combination, becomes one ſingle force, acting in one ſingle direction, and producing a determinate degree of velocity, to be combined with the attractive force at the next ſucceeding inſtant. If then we ſuppoſe the attraction at once to ceaſe at any point of the orbit, the body will fly off in the direction in which it was moving at that inſtant, and with the ſame velocity. From whence it appears, that the effect of the projectile force will remain with the body, though the line of direction in all caſes, and the velocity alſo in elliptical revolutions, be changed at every inſtant. Therefore univerſally, whatever may be the velocity of the body at any point of the orbit, or whatever be its direction, the firſt projectile force muſt always enter into the compoſition of thoſe forces which generate that velocity, and cauſe that direction.

It has alſo been demonſtrated by writers on central forces, that as the body approaches the center, the centrifugal force increaſes in a greater proportion than the centripetal; the centripetal force being inverſely as the ſquare of the diſtance, but the centrifugal inverſely as the cube of the diſtance. Hence it is eaſy to conceive, how the centrifugal force gets the better of the centripetal, as the body approaches towards the center, and *vice verſa*, without ſuppoſing "the effect greater than "the cauſe that produces it." (a)

(a) The whole difficulty here ſeems to have ariſen from a miſconception of what is meant by a centrifugal force. It may not therefore be improper to give a ſhort explanation of it. If at any point of the orbit the attraction be ſuppoſed to ceaſe, it is evident, that the body will fly off in the direction in which it was moving at that inſtant. Hence it appears, that, while the gravitating force acts, there is a continual reſiſtance to it, in a contrary direction. Now this reſiſtance to the attractive force, in all the different parts of the orbit, is called the centrifugal force of the body, and is always in the above-mentioned proportion to the diſtance

The ſeveral effects of a central force, acting on a planet, or a comet in its orbit, have been ſo clearly explained by many writers on that ſubject, that a general demonſtration of them is quite unneceſſary. But as there ſtill may be ſome of Mr. Brydone's opinion, it may not be amiſs to ſhew, that neither the planets, nor the comets are actuated by a repulſive force. In order to this, let S (Fig. 2.) repreſent the ſun, P C Q a part of the orbit of a comet of which C is the perihelion, and let C T be perpendicular to S C. While the comet moves from P to C, Mr. Brydone allows, that it is attracted by the ſun; let us now ſuppoſe, at the inſtant the comet arrives at C, the gravitation towards the ſun to ceaſe, and

tance from the center. When this force, or reſiſtance, is equal to the force of attraction, the body revolves in a circle. If it be greater or leſs than the attraction, the body reſpectively recedes from or approaches to the center. The centrifugal force therefore is clearly diſtinct from the projectile, or that force which being ſucceſſively combined with the attractive is, as was above explained, the actual phyſical cauſe of the motion in the orbit. It is indeed, if we may ſo ſpeak, always a part of that force: it is ſuch a part of it, at any given point of the orbit, as is reducible to a force acting in the direction oppoſite to that of the attraction at ſuch point.

neither attraction nor repulſion to take place; then it is evident, that the comet will go off in the right line C T, that is, in the direction, and with the velocity it had acquired at C, according to the firſt law of nature. But if, when the comet arrives at C, we ſuppoſe a repulſive force to take place, it is very evident that the comet will be driven further from the ſun than it would have been, if no repulſion had taken place; conſequently it will be always without the line C T, and deſcribe the curve C q, convex towards the ſun. Now it is well known, that all the comets hitherto obſerved deſcribe orbits concave towards the ſun, and always paſs between the lines C S, and C T, therefore they muſt be attracted by the ſun, both in their acceſs to, and receſs from it.

But, leaving Mr. Brydone's objections, we may a little further examine the commonly received theory of comets, and we ſhall find, that it is very imperfect, and liable to ſome other objections. The comet that was ſeen in the year 1682 was ſuppoſed to be the ſame that appeared in the years 1607 and 1531, and conſequently to have completed each of its periodic revolutions in about 75 years and a half.

a half. It ſhould therefore have appeared again in the year 1758; and it was much expected by aſtronomers at that time. But though a comet was obſerved that year, the circumſtances attending it evidently ſhewed, that it was not the ſame that appeared in 1682. This ſeems to furniſh an unanſwerable objection to the preſent theory of comets, and ſhews that the predictions of the periodical returns of theſe bodies are not to be depended on. And the neceſſary conſequence ſeems to be, either that the motions of the comets are ſome way or other diſturbed, or that their orbits are not elliptical.

It is allowed, that ſome of the comets recede to a very great diſtance from the ſun. If therefore their orbits are elliptical, they muſt be very excentric. Now one can hardly help ſuppoſing, that the proportion between the diſtance of a comet from the ſun, at its aphelion, and its diſtance from the neareſt fixed ſtar, muſt be conſiderable enough to produce a ſenſible effect upon its motion, and occaſion ſome ſmall change in its orbit. Let us ſuppoſe then, that when a comet is in its aphelion its diſtance from the neareſt fixed ſtar is 100

times

times its diſtance from the ſun; then the gravitation towards the ſtar will be to the gravitation towards the ſun, as 1 to 10000. Now even this ſmall action muſt, in a number of revolutions, occaſion ſome little alteration in the orbit. For if we ſuppoſe the ſtar to be ſituated in the axis of the orbit produced, the gravitation of the comet towards it will ſomewhat lengthen the orbit at every revolution; and therefore the comet, when it returns to its perihelion, will paſs ſomewhat nearer to the ſun than before. This approach will occaſion a greater velocity, and of courſe cauſe it, at the next revolution, to recede ſtill further from the ſun, and conſequently to be ſtill more attracted by the ſtar. And thus, after a number of revolutions, the attraction towards the ſtar will become conſiderable, and the orbit will be very ſenſibly altered. Again, if we ſuppoſe the ſtar to be ſituated out of the plane of the orbit, the attraction of the ſtar will not only lengthen the orbit, but will alter the poſition of its axis, and its inclination to the ecliptic at every revolution. *(a)*

(a) I apprehend the effect of a ſtar's attraction on a comet, would be ſomewhat ſimilar to the above: though I have

If we conſider the comets as acted upon in this manner, ever ſince the creation, we ſhall be led to think, that their orbits would not only be greatly lengthened, but that ſome of them would have, 'ere now, been attracted among the fixed ſtars, perhaps never to return again into our ſyſtem. In like manner we might ſuppoſe, that other comets, primarily belonging to other ſyſtems, would be attracted by our ſun, and after a conſiderable time would be brought into our ſyſtem. But, upon the whole, this ſuppoſition does not appear agreeable to that unity of deſign, which is viſible throughout the univerſe. I am therefore rather inclined to ſuppoſe, that the comets do not move in elliptic orbits at all; but that, after

---

not examined the matter with ſufficient ſtrictneſs to ſay preciſely, what would be the effect of ſuch attraction. This action of the ſun and ſtar upon a comet may appear in ſome meaſure ſimilar to the action of the earth and ſun upon the moon in its orbit. But the effect upon the whole muſt be conſiderably different; for the ſun attracts both the earth and moon, and the diſtance of the moon from the earth is increaſed by that attraction at the oppoſition as well as at the conjunction; whereas the attraction of the ſtar can have no *ſenſible* effect upon the ſun, neither can the diſtance of the comet from the ſun, at, or near, its perihelion, be any way altered by ſuch attraction.

after having arrived at their perihelion, they recede from the ſun in parabolic, or hyperbolic curves, 'till they get within the attraction of the fixed ſtars, when they will deſcribe more complex curves; and being attracted near to ſome ſtar, may acquire a velocity ſufficient to carry them off again in parabolas or hyperbolas.

If a body be projected from the ſurface of the earth, in a direction perpendicular to the horizon, and with a velocity ſufficient to carry it about ſeven miles in a ſecond of time, that body will continue to aſcend for ever in a right line, unleſs its motion be interrupted by the attraction of ſome other body. For though its velocity be continually retarded by the power of gravity, yet as this power decreaſes in proportion as the ſquare of the diſtance increaſes, it will never be able entirely to overcome the motion ariſing from the original impulſe, ſo as to bring the body back again to the point from which it was projected. If a body were projected with the ſame velocity in any other direction, it would go off in a parabola, having the center of the earth for its focus. If it were projected with a velocity ſomething leſs than this, it would deſcribe a very excentric ellipſis. But if the velocity were greater than the above-mentioned, the body would deſcribe an hyperbola; all which has been fully demonſtrated by writers on this ſubject. (a) In like manner, a body at any diſtance from the ſun may be ſuppoſed to be projected with a velocity ſufficient to carry it off from the ſun, either in a right line, or in a parabolic, or hyperbolic curve. If therefore the velocity of a comet at its perihelion be equal to, or greater than that which at ſuch diſtance would cauſe it to aſcend continually in a right line, it muſt neceſſarily go off in a parabola, or hyperbola.

Now as the apparent velocity of many of the comets is exceeding great, though their diſtance from the ſun be at the ſame time nearly, or perhaps altogether, as great as that of the earth, one would ſuppoſe, that their real velocities are ſufficient to carry them off in one or other of the above-mentioned curves. The comet obſerved by Mr. Brydone at Palermo, ſeems to be an inſtance of this kind. For that comet deſcribed an arc of more than 50 degrees in leſs than 24 hours, one extremity of which arc was nearly oppoſite to the ſun; conſequently its real velocity muſt be very great, though its diſtance from the ſun was at the ſame time greater than that of the earth.

(a) As the ſeveral demonſtrations of theſe theorems, from firſt principles, conſiſt of a great number of propoſitions, I decline giving them at length, and chuſe rather to refer the reader to Sympſon's, Emerſon's, or Maclaurin's Fluxions; where he will find them inveſtigated, or demonſtrated, upon principles as certain as the elements of Euclid.

The comet, that appeared in December 1743, and in January and February following, was obſerved by Mr. Joſeph Betts; (a) and, according to his computation, the perihelion diſtance of that comet was about one fourth of the earth's mean diſtance from the ſun. Now the earth's mean velocity, or the velocity with which a body would revolve in a circle at the mean diſtance of the earth from the ſun, is about 970 miles in a minute, and the velocity with which a body would revolve in a circle at one fourth of that diſtance is 1940 miles in a minute, or double of the earth's mean velocity. But, for the ſake of a round number, we will ſuppoſe the velocity with which that comet might have deſcribed a circle about the ſun, at its perihelion diſtance, to be 2000 miles in a minute, then the velocity neceſſary to carry off a body in a parabola being to the velocity in a circle at the ſame diſtance in the ſubduplicate ratio of 2 to 1, we find the velocity which would have carried off that comet in a parabola to be about 2828 miles in a minute. But this velocity falls far ſhort of the velocity aſcribed to that comet; for, according to the remarks of the above-mentioned gentleman, its velocity was not leſs than 9000 miles in a minute. How far theſe obſervations and calculations are to be depended upon, I cannot pretend to determine; but I think they afford us full reaſon to conclude, that the velocity of that comet was ſufficient to carry it off from the ſun in a hyperbola.

(a) See Hutton's Edit. Ladies Diary, Vol. II. Page 164.

In order to ſupport this opinion, I might produce other inſtances of the ſame kind; but I apprehend the greateſt part of the obſervations upon comets that are recorded are too inaccurate to found a demonſtration upon. I ſhall therefore leave them, and endeavour to take a view of the conſequences that muſt neceſſarily follow the admiſſion of this hypotheſis.

If then we conſider the comets as deſcribing parabolic, or hyperbolic curves, it will eaſily appear, that when a comet has paſſed its perihelion, it will continue to fly off, in a parabola, or hyperbola, 'till it comes within the attraction of ſome fixed ſtar. This attraction will give it a new direction, and increaſe its velocity, 'till it comes to an apſis below that ſtar; when it may again fly off, either in a parabola, or hyperbola, 'till it arrives at another ſyſtem, and ſo on, 'till it has viſited many different ſyſtems, and approached towards many different centers.

As the direction of a comet, after it has paſſed its perihelion, is *to us* perfectly contingent, we may ſuppoſe it to tend towards any point in the univerſe, at pleaſure. In the firſt place therefore, let us ſuppoſe it to tend almoſt directly to one of the neareſt fixed ſtars. In this caſe, the attraction of that ſtar will accelerate its velocity at a ſurpriſing rate; and the comet approaching the ſtar almoſt in a right line, will come to an apſis near that part of the ſtar's ſurface which is fartheſt from the ſun; and conſequently will aſcend again from that ſtar, almoſt in a right line, and nearly in a contrary direction to that in which it deſcended to it. Again, let us ſuppoſe the direction of a comet to tend towards a point ſituated at a great diſtance from the ſtar, though not ſo far as to be within the *ſenſible* attraction of any other ſtar. In this caſe, when the comet comes within the attraction of the ſtar, its direction will be conſiderably altered, and it will come to an apſis at a conſiderable diſtance from the ſtar. Thus, by varying the ſituation of the point towards which the direction of the comet tends, we may imagine it to come to an apſis at any diſtance from the center of attraction, provided that diſtance does not carry it within the attraction of ſome other center. But we may go ſtill farther, and ſuppoſe the direction of a comet to carry it towards a point ſituated at *almoſt* an equal diſtance between two of the neareſt fixed ſtars. In this caſe, the comet, being *almoſt* equally attracted by thoſe ſtars, will paſs on *nearly* in a right line towards ſome other ſyſtem; the orbit however will be *ſomewhat* concave towards that ſtar by which it is moſt attracted; and the point of the orbit, through which a right line joining the two ſtars paſſes, may be conſidered as an apſis.

Thus, under various circumſtances, we may eaſily conceive the effects that muſt be produced, upon the ſuppoſition that comets move in parabolic, or hyperbolic curves. If we now take a view of the various phænomena which have been actually obſerved in the cometary motions, we ſhall find ſuch a ſimilarity between them and the above-mentioned conſequences, as will afford us ſtill further reaſon to favour this opinion. The comet which appeared in the year 1680 ſeems to correſpond with the firſt caſe mentioned. For, according to our accounts of that comet, it approached the ſun almoſt in a right line, and coming to an apſis near the ſun's ſurface returned back almoſt in a right line, and towards the ſame point in the heavens from whence it came. The phænomena of other comets alſo, whoſe direction ſeems to carry them conſiderably wide of the ſun, perfectly correſpond with the neceſſary conſequences of this hypotheſis. But what more particularly favours this opinion is, that many comets have been diſcovered by the teleſcope, which have never become viſible to the naked eye. Theſe comets, in all probability, have gone off again without deſcending within the orbit of Saturn; ſo that we can ſcarcely conſider them as belonging to our ſyſtem. We may with much more reaſon ſuppoſe, that ſuch a comet, after having left one ſyſtem, is carried, by the direction of its orbit, far wide of our ſun; but coming within its attraction, is drawn juſt to the verge of our ſyſtem; its velocity, however, being very great, in proportion to the diſtance and the power of the ſun's attraction, it flies off again towards ſome other ſyſtem.

To this hypotheſis it may be objected, that, when a comet is carried off to a great diſtance from the ſun, its motion will be ſo ſlow, that it would not arrive at another ſyſtem in many years, or perhaps ages. But here let it be obſerved, that the power of gravitation towards the ſun can ſubduct from the velocity of a comet only a certain determinate quantity. If a body, as before obſerved, is projected directly from the ſun with a certain velocity, it will continue to riſe for ever in a right line, in oppoſition to the power of gravity. Now the action of the ſun can never ſubduct from a body in motion a velocity greater than that which would cauſe it to riſe perpetually in a right line; for if it could, it muſt certainly bring it down again. But we find, that the velocity of ſome comets at their perihelion is conſiderably greater than that, which, at that diſtance, would cauſe them to aſcend continually in a right line; therefore, whatever may be their diſtance from the ſun, their velocity muſt be always, at leaſt, equal to the exceſs of their velocity at their perihelion, above that velocity, which, at that perihelion diſtance, would cauſe them to aſcend continually in a right line. Now this exceſs, as we have already found,(a) may amount to ſome thouſand miles in a minute; a velocity, ſurely, ſufficient to carry a comet from one ſyſtem to another, in no very conſiderable length of time.

But there is ſtill another circumſtance in the in the cometary motions which may deſerve our attention. The planets, we know, revolve round the ſun in orbits whoſe planes are all within the Zodiac, that is, within the ſpace of a few degrees, and conſequently make very ſmall angles with each other. They likewiſe all move in one direction, from weſt to eaſt. The motions of the ſeveral ſecondary planets round the primary are alſo in the ſame direction, and their orbits make very ſmall angles with each other. All theſe bodies, by the ſimilarity of their original projections, and their mutual gravitations towards each other, and towards their common center, are made to preſerve their relative poſitions in the ſyſtem, and to maintain an equilibrium throughout the whole. Thus, in the motions of the planets, all is order and uniformity: and every circumſtance attending them conſpires to ſhew, that they conſtitute of themſelves one entire ſyſtem. With reſpect to comets, on the contrary, all is irregularity and apparent contingency. They move in almoſt every direction. The planes of their different orbits make angles of all dimenſions with the plane of the ecliptic. Nor is there the ſmalleſt analogy between the motions of theſe bodies and thoſe of the planets, except that they obſerve, as they neceſſarily muſt, the ſame laws of gravity, when they come within the ſun's attraction.

(a) Page 57.

I know not what weight theſe ſeveral circumſtances, which I have mentioned, may have upon the minds of others. With me I own, taking them altogether, they produce little leſs than conviction, that the comets are not original, or permanent parts of our ſyſtem, that they do not revolve round the ſun as their only center of attraction, but that, no doubt for wiſe purpoſes, they were originally projected in ſuch directions, and with ſuch degrees of velocity, as to be made ſucceſſively to traverſe many different ſyſtems, to move in new directions, and deſcribe new orbits, as they are ſucceſſively attracted towards different centers.

But it may be thought, that this hypotheſis tends to diſcourage any further enquiries into the theory of the cometary motions, becauſe, if it be true, the prediction of a comet's return will be abſolutely impoſſible. And doubtleſs it will, in ſome meaſure, have this tendency. For it can be of no uſe to ſearch for that which does not exiſt; and if comets do not regularly return, all attempts to diſcover the time of their appearance will be vain and fruitleſs, tending only to weaken the credit of aſtronomical enquiries, and to eſtabliſh the prejudices of the vulgar. It is therefore to be wiſhed, that, when any new comet appears, aſtronomers would endeavour, by every poſſible method, to diſcover whether there be any foundation for the hypotheſis here given. And if, upon examination, it ſhould be found true, and the prediction of a comet's return be rendered impoſſible, mathematicians may ſtill find ſufficient employment, in determining the particular ſpecies and dimenſions of the curve which a comet actually deſcribes.

There may alſo be opened a larger field for contemplation than we, at firſt, may imagine, or even than the commonly received theory will admit. If a comet viſits any ſyſtem, and goes off again without returning, it is evident that it muſt occaſion ſome little motion, or perturbation, in the center of gravity of that ſyſtem. Poſſibly therefore, the ſmall attraction of one ſyſtem towards another may by this means be counteracted. And as comets are found to move in many different directions, their attractive power may ſerve to balance any tendencies that the ſeveral ſyſtems, into which they are carried, may have to different or contrary directions. And thus, by the interpoſition of theſe wandering bodies, and their ſucceſſive deſcent towards various centers, every ſyſtem may be kept in its original poſition, and an equilibrium be preſerved throughout the univerſe.

What therefore, at firſt ſight, has the appearance of mere contingency, may, upon further examination be found to be the neceſſary effect of the ſame general principles, acting by the ſame general laws as obtain throughout every part of nature, and be juſtly ranked amongſt the moſt ſtriking inſtances of magnificent and conſummate deſign.

APPENDIX

TO THE

OBSERVATIONS ON LIGHT.

SINCE the foregoing Obſervations on the Nature and Properties of Light were printed, an objection has been mentioned to me againſt the doctrine which I have endeavoured to eſtabliſh, as being contradictory to a principle laid down by Des Cartes, Sir Iſaac Newton, and almoſt all other writers upon optics, viz. that the velocity of light is increaſed by its paſſage through a refracting medium, and *that* in proportion to the denſity of ſuch medium. The neceſſary conſequence of which poſition is, that, if light be produced, as we have ſuppoſed, by the velocity of the particles, their lucidity will be increaſed inſtead of being diminiſhed, in conſequence of their paſſing from a rarer to a denſer medium. An obſervation or two upon the nature of refraction, will, I hope, ſufficiently obviate this objection.

It ſeems clear, that the refraction of light cannot be cauſed by the reſiſtance of the particles of the refracting medium, as Des Cartes has endeavoured to prove. For in that caſe, the ray would not be refracted towards the perpendicular, as we find to be the fact, but the contrary, as in all other inſtances of bodies paſſing from a rarer medium to a denſer. It is therefore generally allowed, that the refraction of light is cauſed by an attractive force acting in a direction perpendicular to the refracting ſurface. And Sir Iſaac Newton ſuppoſes, that this power of attraction, in the ſeveral particles of the refracting medium, extends to a very ſmall diſtance in every direction from ſuch particles. The ſpace within which this attractive power of any particle acts he calls the ſphere or ſpace of activity of ſuch particle.

Now, if a particle of light approaches a refracting ſurface in an oblique direction, as ſoon as it arrives within the ſphere of attraction of thoſe particles of the refracting body which compoſe its ſurface, the line of its direction will be changed by the action of thoſe particles, and bent towards the perpendicular. But when the particle has paſſed the ſpace of activity of thoſe particles of the body which are ſituated in its ſurface, its direction will, from that inſtant, remain unaltered. For, being now attracted equally on all ſides, it will neceſſarily paſs on in a right line towards the other ſurface of the body.

Moreover, as the attraction of the refracting body acts in a direction perpendicular to its ſurface, the perpendicular velocity of the ray, or ſuch a part of its velocity as is reducible to a perpendicular direction, will be increaſed, and as the parallel velocity remains the ſame, the abſolute velocity will conſequently be increaſed. If *no reſiſtance* therefore be ſuppoſed to take place, the ray, having paſſed the ſpace of activity of the firſt ſurface, will continue to paſs on, uniformly, with that increaſed velocity, 'till it arrives near the other ſurface of the refracting body, where, being again equally attracted, in a contrary direction, it will emerge from the body in a direction parallel to that of its firſt incidence, and with the ſame velocity.

This is the Newtonian doctrine, and it has our full aſſent. It by no means, however, follows from hence, that the particles of light meet with no reſiſtance from the particles of the refracting medium, after they have paſſed the ſpace of activity of the particles which compoſe its ſurface. (*a*) For the attraction being now equal on all ſides, and conſequently without any effect, there remains nothing to prevent the ſame reſiſtance of the particles of the medium to the particles of light, as obtains in the caſe of all other bodies paſſing through a medium, and *that* in proportion to the denſity of ſuch medium. Though therefore the velocity of a particle, at the inſtant it has paſſed the ſpace of activity of the firſt ſurface, is, doubtleſs, increaſed; yet, in the next ſucceeding inſtant, its velocity will be ſomewhat retarded by the reſiſtance of the medium, and ſo on, more and more, 'till it arrives at the ſecond ſurface of the medium; where the attraction being equal and contrary to that at the firſt ſurface, the particle will, upon the whole, emerge with a leſs velocity than at its incidence.

From

(*a*) The effect of the reſiſtance at the ſurface is overcome by the attraction.

From this plain ſtate of the matter, the doctrine, which we have endeavoured to eſtabliſh, appears to be perfectly conſiſtent with the Newtonian theory. And indeed Sir Iſaac Newton himſelf, though he has not purſued this matter by experiments, ſeems clearly to be of opinion, that the velocity of light ſuffers conſiderable alteration in its paſſage through refracting bodies. For, ſays he, (*a*) "Nothing more is requiſite for putting the rays "of light into fits of eaſy reflexion and eaſy "tranſmiſſion, than that they be ſmall bodies "which by their attractive powers, or ſome "other force, ſtir up vibrations in what they "act upon, which vibrations being ſwifter than "the rays, overtake them ſucceſſively, and "agitate them ſo as by turns to increaſe and "decreaſe their velocities, and thereby put "them into thoſe fits."

I ſhall conclude theſe obſervations, with remarking the impropriety of all attempts to account for the operations of nature by metaphyſical principles. Thus Leibnitz and others have endeavoured to explain the refraction of light by the application of a principle purely me-

---

(*a*) Optics, Page, 347.

metaphyſical, viz. "That nature takes always "the ſimpleſt or eaſieſt way to accompliſh "its purpoſes." Who does not at once ſee, that all principles of this kind are totally miſapplied in matters of phyſical inveſtigation; that they do not in the ſmalleſt degree tend to advance our real knowledge of nature, nor can give us any ſatisfaction or even aſſiſtance in tracing effects to their cauſes. They may indeed be the reſult of our enquiries into the operations of nature, but they can be of no uſe in the way of explaining and accounting for them; being founded ſolely on our previous knowledge of the actual phyſical cauſes of ſuch operations.

FINIS.

Fig. 1.

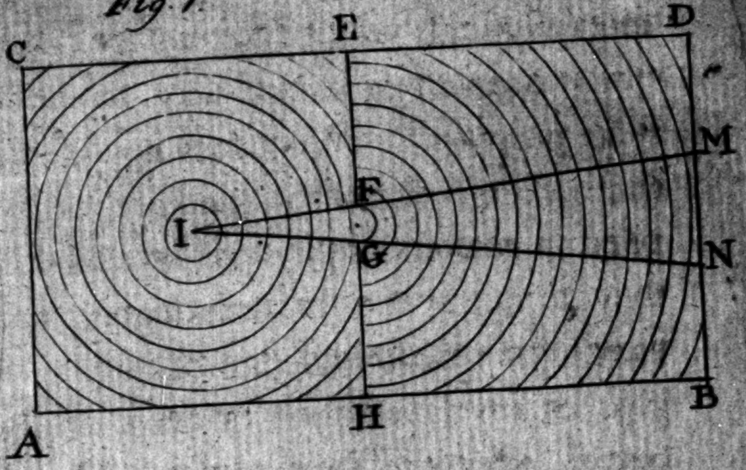
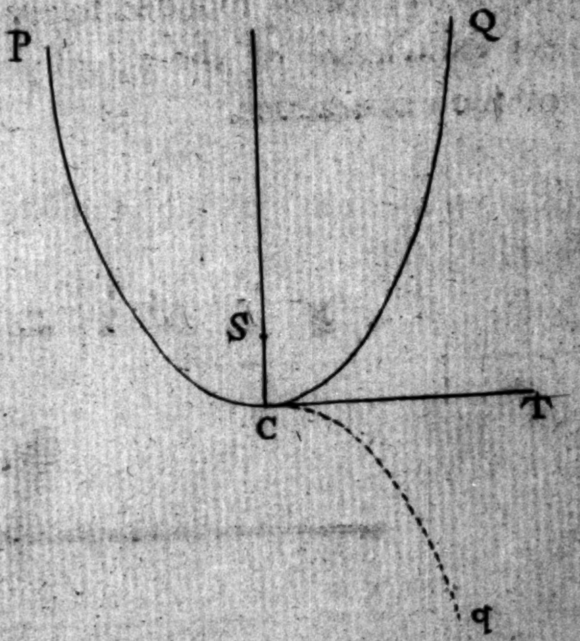


Fig. 2.



BRITIS
9 MAY
MUSEU

15